CHAPTER 10

GROUNDING

Section I—CONSIDERATIONS

10-1. Basic principles of grounding.

Grounding is provided to limit potential (voltage) differences to values that will not cause undue hazards to personnel and equipment. A ground system which provides adequate current-carrying capacity and a low-resistance path to an earthing connection will dissipate, isolate, or disconnect overpotential areas resulting from fault overcurrents or surge overvoltages. A ground path can consist of single or multiple conductors whose connection provides adequate thermal and conductance capacities. The earthing connection is generally a metallic electrode such as a rod, a water pipe, a counterpoise, or a ground grid system installed below grade.

a. Electrode resistance. The resistance of a ground electrode is primarily determined by the earth surrounding the electrode. Test data given in IEEE *142* indicate that about 90 percent of the total resistance of a ground lies within 6 to 10 feet (1.8 to 3 meters) from the electrode. The diameter of the rod has only a negligible effect on the resistance of a ground. The resistance of the soil is dependent upon the type of soil and its moisture content. Electrodes should be long enough to penetrate a relatively permanent moisture level and should extend well below the frost line.

b. Factors which can degrade initial good grounds. Tests should always be made at times when the surrounding soil can be expected to have the least moisture. The following factors indicate the importance of continuous periodic testing of grounding systems.

(1) Water tab1es are gradually falling in many areas.

(2) There are more underground installations of nonmetallic pipes and conduits, which do not provide low-resistance ground connections.

(3) Electric systems are continually expanding with an associated fault current increase which may require a decrease in grounding resistance.

(4) Corroded connections may increase the resistance.

1O-2. Grounding provisions.

Maintenance personnel deal with two types of grounding systems: permanent and temporary.

a. Permanent grounding systems. Permanent grounding is provided for the efficient, effective, safe operation of electrical power systems.

(1) *Safety.* Equipment grounding, which is the grounding of all exposed or accessible noncurrent-carrying parts of electrical devices and equipment, reduces the hazards of contact by personnel.

(2) *System operation.* System grounding, which is the grounding of one conductor point on an electrical circuit, stabilizes the voltages to protect the equipment and provides a basis for adequate protective relaying.

b. Temporary grounding. Temporary grounding is the personal protective grounding, which is provided to protect persons engaged in de-energized electric line maintenance.

Section II-MAINTENANCE

1O-3. Grounding maintenance safety.

Extreme care must be exercised in inspecting, maintaining and testing grounds and ground systerns. Never open a grounding connection unless the connected equipment is deenergized, or an adequate safety bypass is provided. Always wear rubber gloves and follow facility safety manual procedures. This applies equally to grounds installed on structural or supporting members, ground connections to equipment enclosures, and neutral grounds of primary or secondary systems. The life and safety of those in the vicinity of electrical facilities depend on how carefully and completely inspections and maintenance of grounds and grounding systems are performed.

10-4. Visual inspection of grounds.

Visual inspection of ground connections to equipment, equipment enclosures, structural members, fencing, and system neutrals should be made at least every 2 years. More frequent inspections should be made where appropriate to the system's size and importance. Loose, broken, or missing connections should be repaired or replaced as required. Connections or connectors showing signs of overheating, as evidenced by discolorations, should be reported, as this may be the result of an improper application or installation. If connections are found to be corroded or rusted, they should be cleaned and corrective measures should be taken to prevent a recurrence of this situation. Excessive amounts of corrosion should be reported, as this may indicate the need for cathodic protection in the area.

10-5. Galvanic corrosion of grounds.

The use of dissimilar metals embedded in the earth in and around generating stations and substations results in the formation of a huge galvanic cell. Steel or galvanized structures, including conduits, cable sheaths, pipes, and structural footings, where used either purposely or inadvertently in the ground system, are subject to galvanic corrosion. Attention should be given to the necessity of providing corrosion mitigation measures under such circumstances.

a. Stainless steel ground rods. Do not use stainless steel ground rods. Their performance can be unpredictable because of their tendency toward localized corrosion.

b. Underground pipe lines. The bonding of interior metallic pipelines to an electrical system's ground provisions of copper (which is required by code) if done incorrectly, can result in galvanic corrosion of the underground pipeline. Installation of a dielectrically-insulated fitting on the pipe above ground, and before the copper ground connection, will eliminate the earth's electrolytic coupling between the underground cable and the ground wire.

Section III-TESTING

10-6. Ground resistance tests.

In addition to visual inspections of grounding systems and connections, resistance measurements will be made periodically to determine whether there is any trend toward an increase in the ground resistance of an installation. Maximum permissible resistance for grounds and grounding systems will be in accordance with departmental standards, ANSI C2, or the National Electrical Safety Code, whichever is lower.

a. ANSI C2 *requirements. No* specific ground resistance is given, except that a single-grounded, individually-made electrode, with a ground resistance exceeding 25 ohms, requires two parallel and interconnected electrodes. Supply stations (dependent upon size) require an extensive grounding system, consisting of either multiple buried conductors or electrodes or both, to limit touch, step, mesh, and transferred potentials in accordance with industry practices. All grounding systems must be designed to minimize hazard to personnel and have resistances low enough to permit prompt operation of circuit protective devices.

b. Departmental standards. Departmental standards will require values ranging from 1 ohm up to a maximum of 25 ohms depending on the size of the system.

c. Measurement records. Continuous records will be kept for all grounding installations, which require a ground resistance of 10 ohms or less, to verify that design resistances are still being provided.

1O-7. Ground value measurements.

The following ground resistance measurements should be made in order to ensure safe operating practices.

a. Measure the ground path resistance of all branches of the grounding system from the point of connection, on the structure, equipment enclosure, or neutral conductor, to the earthing connection. The earthing connection may be the top of a single ground rod, a water pipe, a counterpoise, or a ground grid.

b. Measure the resistance of the earthing connection whether it is a ground rod, a water pipe, a counterpoise, or a ground grid to the earth itself.

c. Wherever the total resistance of the total ground circuit is in excess of the values established, measure resistance of individual portions of the circuit to determine the point or points where resistance is excessive and corrective action can be taken.

d. Measure resistance between gates and gateposts to ensure that flexible ground connections are adequate. Resistance higher than one-half ohm indicates a deficiency.

e. Measure resistance between operating rods and handles of group-operated switches and the supporting structure to determine that the flexible connections are adequate. Resistance higher than one-half ohm indicates a deficiency.

f. Measure resistance of all bonds between metallic-cable sheathing and its ground path. Resistance higher than one-half ohm indicates a deficiency.

g. Testing of grounds may create hazardous conditions if care is not exercised. Fault or surge currents can build up dangerous voltages between the point of equipment ground connection and the point of the earthing connection. Rubber gloves, blankets, and such are recommended for the protection of personnel. Ground resistance measurements should never be attempted during lightning storms.

10-8. Methods of measuring ground resistances.

All methods of measuring ground resistance are similar in that a suitable source of current is necessary. Auxiliary reference grounds and test instruments are necessary for ANSI/IEEE 80 and ANSI/IEEE 81 methods.

a. Minor grounding installations. The following methods are suitable for measuring the resistance of isolated ground rods or small grounding installations. Precision in measurements is difficult to obtain. Normally an accuracy of 25 percent is sufficient, since the surrounding soil will not have consistent values of temperature, moisture, and depth.

(1) *Portable ground testing instruments.* A usual way to measure the ground resistance is with a low-range, self-contained, portable earth-tester instrument such as the "Megger" Ground Tester or Ground Ohmer. The manufacturers' instructions should be followed in the use of this instrument. The two most common methods of measuring the ground resistance with this type of instrument are the direct-reference or two-point method shown in figure 10-l and the auxiliary ground method shown in figure *10-2.*

(2) *Three-point method.* The three-point method of measuring ground resistance requires two auxiliary grounds, similar to those required with portable ground testing equipment, except that each auxiliary ground should have a resistance approximately equal to the ground being tested. This arrangement is shown in figure 10-3. The ground rods should be driven 8 to 10 feet (2.5 to 3 meters) into the earth and spaced not less than 50 feet (15 meters) apart. Three separate tests are made to determine the resistance of each of the series circuits when composed of only two grounds. The unknown resistance may then be calculated as follows by equation 10-l.

$$R_A = \frac{R_1 + R_2 - R_3}{2} \qquad \text{(eq. 10-l)}$$

Actual resistances may be determined by using one of the following methods.

(a) AC voltmeter-ammeter method. The connections for the ac voltmeter-ammeter test are shown in figure 10-3. The resistances of the ground circuits are determined from the meter readings and these values are then used in calculating R_A. Stray alternating currents of the same frequency as the test current, if present, will introduce some error in measurements.

(b) DC voltmeter-ammeter method. A dc voltmeter-ammeter method may also be used to determine the resistance of each pair of grounds in series. Like the ac method, it is limited to locations where power is available or where a battery source may be used with the regulating apparatus required to control the current flow. The line supply-

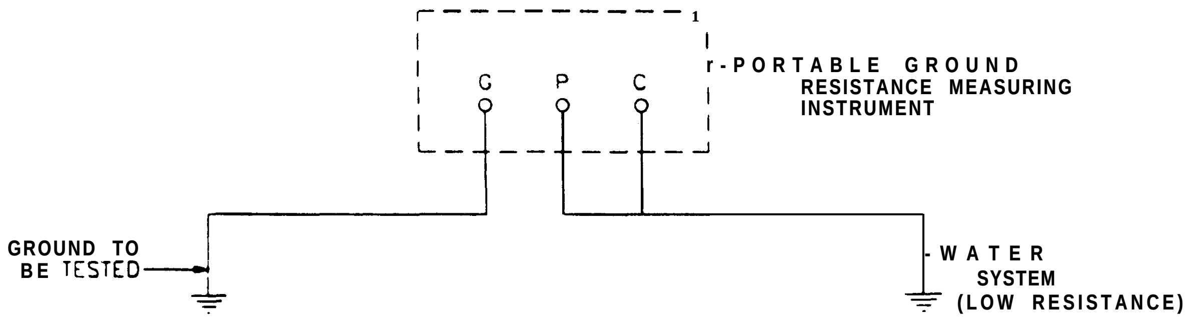


Figure 10-l. Direct-reference or two-point ground test

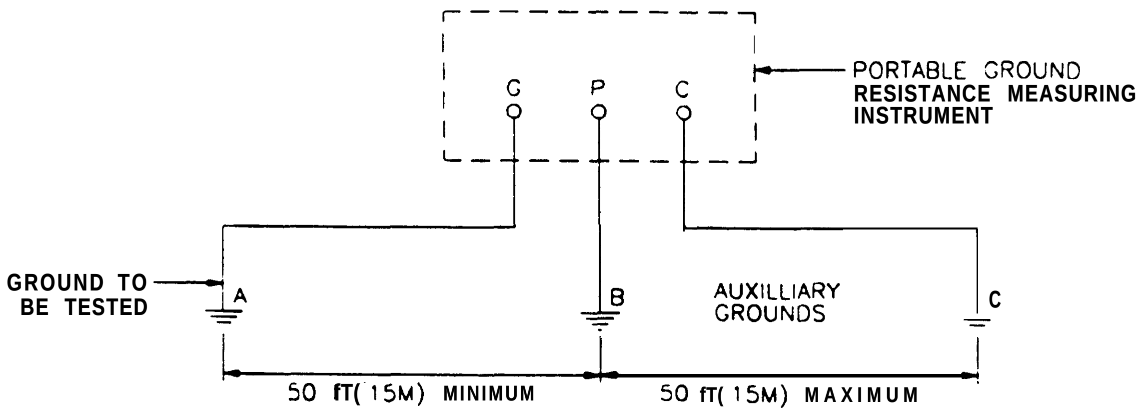


Figure 10-2. Auxiliary ground method

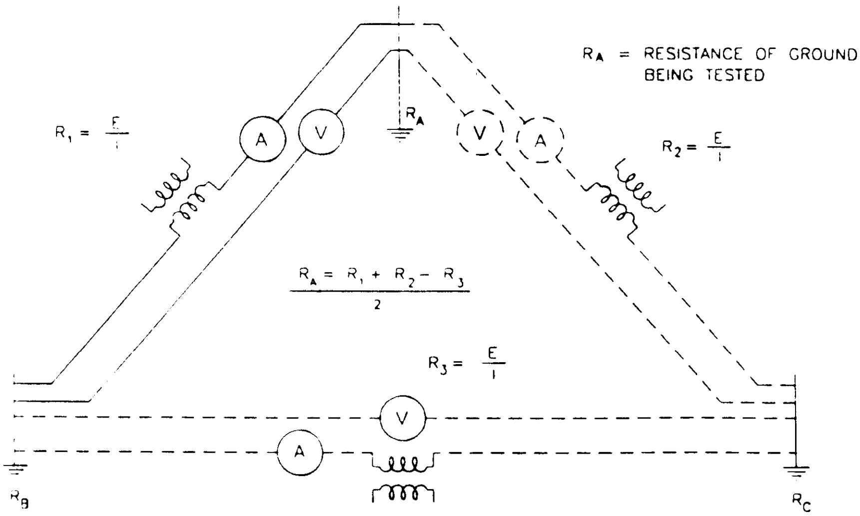


Figure 10-3. Ground resistance measurement, three-point method

ing the current must be free from grounds to minimize the effect of cross-currents. To compensate for the effect of stray dc voltage currents in the area, readings should be made at both polarities.

b. Major grounding installations. Where accurate measurements of extensive low-resistance grounding systems are required, more elaborate test methods and equipment are needed using considerably larger separation distances between test electrodes. Normally large facility substations are tested with the fall-of-potential method in accordance with ANSI/IEEE 81 requirements. Figure 10-4 shows a field setup for this method and the ground resistance curve. The resistance shown on the flat part of the curve is taken as the resistance of the ground. The self-contained earth tester instrument shown should be used rather than a voltmeter-ammeter combination, as the earth tester is designed to eliminate the effects of stray currents. The primary advantage of this method is that potential and current electrodes (probes) may have substantially higher resistance than the ground system being tested without significantly affecting the accuracy of the measurement.

(1) *Major substations.* To allow for seasonal variations it is recommended that tests be made at the same time each year or for each season of the year to allow for accurate comparison.

(2) *Procedures.* Tests should be performed in accordance with written procedures. Provide adequate safety precautions as all electrical conducting paths for overvoltage and fault currents are connected to the substation grid.

10-9. Method of reducing ground resistances.

Ground tests may indicate that the ground resistance exceeds safety requirements. Adding rods, increasing rod lengths, soil treatment, or a combination of these methods may be necessary. Also see IEEE 142 for additional information on the effect of these changes.

a. Adding rods. An easy and preferable method of reducing the resistance is to provide more rods. For example, two ground rods, properly spaced and connected in parallel, should have a combined resistance on the order of 60 percent of the resistance of one rod; and for three rods, 40 percent of that resistance. In general, proper spacing of rods means placing rods at least one rod length apart.

b. Increased rod length. Providing longer rods is particularly effective where low-resistance soils are too far below the surface to be reached with the normal rod lengths of 8 to 10 feet (2.5 to 3 meters). The amount of improvement from longer rods depends on the depth of the low-resistance soils. A rather sharp decrease in the measured resistance is usually noticed where the rod has been driven to a low-resistance soil level. Soil resistivity usually (but not always) decreases with depth because there is normally an increased moisture content.

c. Soil treatment. A method called salting has traditionally been used to treat the soil around ground rods.

(1) Sodium chloride, calcium chloride, magnesium, and copper sulfate are all used as treatment. Bentonite, a natural clay, works well, except in a very dry environment. A pre-packaged mixture of 75 percent gypsum, 20 percent bentonite, a 5 percent sodium sulfate. is recommended. Ground rods can also be encapsulated in concrete rather than using a soil treatment.

(2) Soil treatment is a reliable and effective method for reducing ground resistance and is particularly suitable for improving a high-resistance soil. The treatment is advantageous where long rods are impractical because of rock strata or other

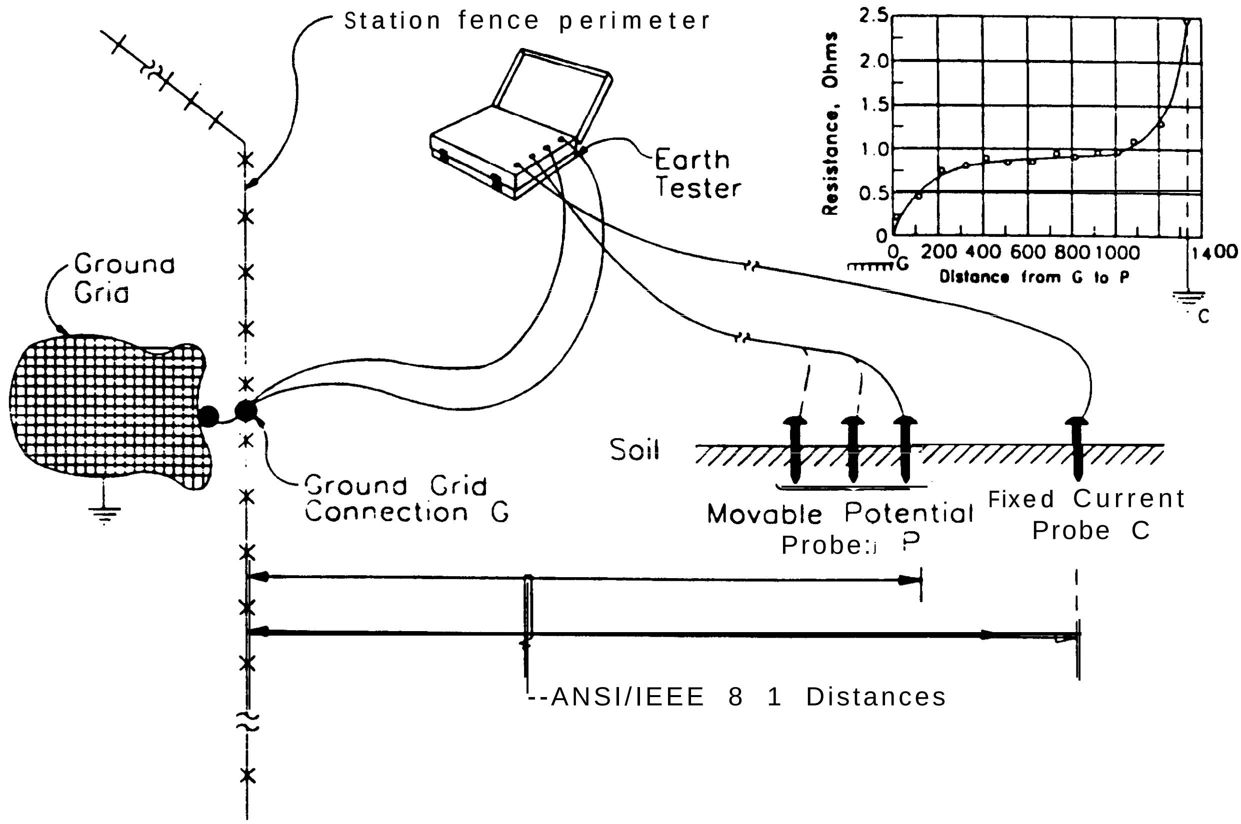
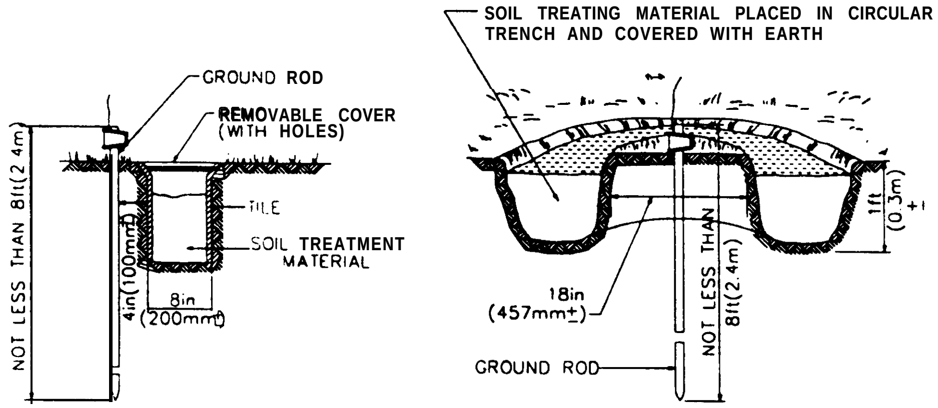


Figure 10-4. Field setup and curve for fall-of-potential method

obstructions to deep driving. There are two practical ways of accomplishing this as shown in figure 10-5. Where space is limited, a length of tile pipe is sunk into the ground a few inches (millimeters) from the ground rod and filled to within approximately 1 foot (0.3 meters) of the ground level with the treating chemical. The second method is applicable where a circular or semicircular trench can be dug around the ground rod to hold the chemical. The chemical must be kept several inches (millimeters) away from direct contact with the ground rod to avoid corrosion of the rod. The first treatment usually requires 50 to 100 pounds (22 to 45 kilograms) of material and will retain its effectiveness for 2 to 3 years. Each replenishment of the chemical extends its effectiveness for a longer period, thus increasing treatment intervals. To start the action promptly, the first treatment of chemical should be flooded.

d. Specialized rods. In lieu of adding additional rods or lengthening rods, a copper tubing grounding system can be used. There is an Underwriters-listed grounding system that uses a 2-inch (50-millimeter) copper tube filled with metallic salts and available in various lengths. Since this method uses metallic salts it is not recommended except as a last resort. The tube is also available as a straight unit, or in an L-shaped configuration which allows the tube to be installed on its side in a shallow trench. Changes in atmospheric pressure "pump" air through the breather holes at the top of the tube. Moisture in the air condenses inside the tube to move slowly down through the bed of metallic salts, providing a self-maintaining low-resistance system with a much greater life expectancy than conventional ground rods.

e. Combination methods. A combination of methods may be advantageous and necessary to provide the desired ground resistance. Adding specialized rods or a combination of multiple rods and soil treatment may be effective. Multiple of longer rods are effective where conditions permit this type of installation.



a. CONTAINER METHOD

b. TRENCH METHOD

Figure 10-5. Methods of soil treatment for lowering of ground resistance